Microelectronic Engineering 87 (2010) 1253–1255

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

NOA 63 as a UV-curable material for fabrication of microfluidic channels with native hydrophilicity

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ARTICLE INFO

Article history:
Received 9 September 2009
Accepted 17 November 2009
Available online 20 November 2009

Keywords:
Assay
Fluorescence
Magnetic particles
Microfluidics
NOA 63

ABSTRACT

In this paper, we propose a method to create a natively hydrophilic microfluidic structure in a fast and simple way using an UV-curable polymer (NOA 63 from Norland Optics). This polymer can provide a substitute to PDMS microchannels offering high reproducibility, elevated fabrication throughput and native hydrophilicity, allowing easier filling of the microchannels with aqueous solutions. We demonstrate the manufacturing of a complete microfluidic system, composed by a NOA 63 body sealed by a NOA 63 membrane, and we study the hydrophilicity and the optical characteristics of the fabricated cartridge.

1. Introduction

The introduction of miniaturized systems for bioanalysis necessitated the need of finding adequate solutions for the fabrication of microfluidic systems [1–3]. In the literature, microfluidic channels are fabricated using a variety of processes and materials. Silicon and glass bulk micromachining is one of the techniques for the manufacturing of microchannels [4]. This technique presents the disadvantages of being relatively complex, and has limitations to the geometries that can be realised (for glass wet etching). Polydimethylsiloxane and SU-8 are materials that have gained a prominent status in the last years. SU-8 is a negative resist developed at the beginning of 1990 [5] and has as major advantage the high realisable aspect-ratio [6]. It is however difficult to remove SU-8 from its support (for instance a silicon wafer) once it has been cross-linked; this creates difficulties in the realisation of free-standing SU-8 microfluidic structures. Polydimethylsiloxane (PDMS) microchannels offer high flexibility and high reproducibility thanks to moulding fabrication techniques. PDMS is for these reasons currently one of the most used materials for microchannel fabrication [7]. However, its native hydrophobicity can be a problem for the filling of the microchannels with aqueous mixtures. Different solutions, like curing or coating the channels, have been proposed in the literature, but the obtained hydrophilicity is limited in time [8,9].

NOA 63 is a clear, colourless, liquid photopolymer that cures when exposed to ultraviolet light. It is used as glue for the bonding of precision optics compounds. We propose its use as a substitute of PDMS for microfluidics. Kim suggested a way to fabricate microfluidic chips in NOA 63 [10]. However, complete characterisation of the produced chips was lacking. High natural hydrophilicity and fast and replicable fabrication are some of the characteristics that make NOA 63 a suitable candidate for microfluidic prototyping. The fabrication process is based on moulding NOA 63 in liquid state on a master mould, cure the photopolymer under UV light and seal the thus created body to a NOA 63 membrane which has been spun on a glass wafer. The process flow is similar to the fabrication of PDMS cartridges, but curing is done through UV light exposure and takes much less time than curing of PDMS.

2. Cartridge fabrication

The master mould for the microfluidic cartridge body consists of a 50 μm high and 200 μm wide SU-8 mesa structure realised on a silicon substrate by standard clean-room fabrication techniques (see Fig. 1a). A secondary PDMS mould of desired height is used to enclose the NOA liquid photopolymer on top of the SU-8 structure. The liquid photopolymer is poured in the mould and UV cured for 140 s, allowing easy unmolding of the cartridge body from the Si wafer (see Fig. 1b). Shorter curing times make complete unmolding impossible, and we observed that incompletely cured NOA stuck to the Si wafer. Longer times increase the elasticity modulus, and the stress induced to the cartridge body during unmolding can, in this case, degrade its geometrical characteristics and damage the channel.

A microchannel sealing membrane is fabricated separately, by spinning the NOA on top of a glass wafer covered with PDMS as

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doi:10.1016/j.mee.2009.11.084

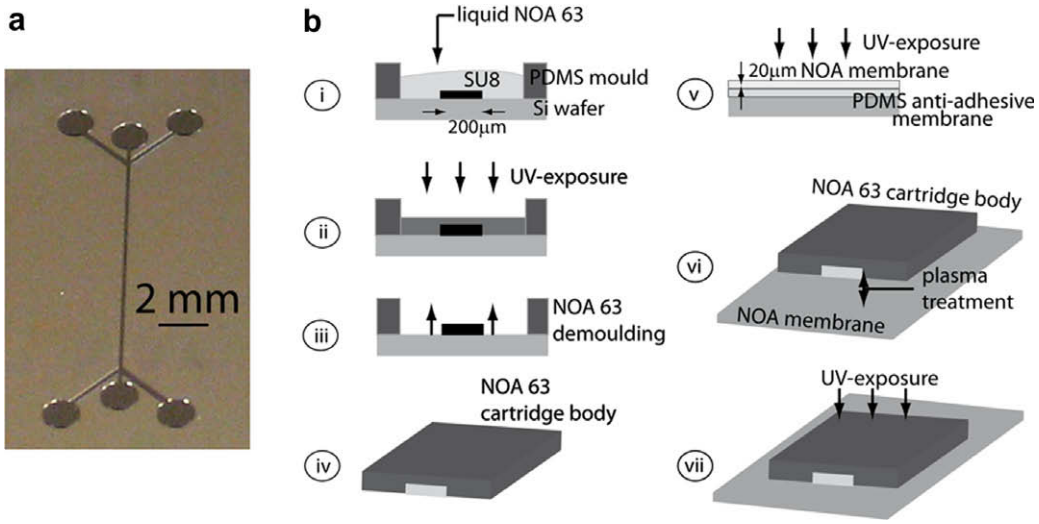

Fig. 1. (a) SU-8 mesa structure used as a mould for the microchannel. SU-8 is deposited and defined by photolithography and standard clean-room processes on top of a standard silicon wafer. (b) NOA 63 cartridge fabrication steps. A body and a membrane are fabricated separately by moulding NOA 63 over the SU-8 mould, and by spinning liquid NOA 63 over a glass wafer. The two parts are then bonded together by means of air plasma treatment (60 s, 20 W) and UV light hard curing (2 h).

an anti-adhesion layer. NOA is mixed with toluene in 8:2 proportion in order to decrease the photopolymer viscosity and allow a more uniform spread. After spinning at 3500 rpm for 40 s, and exposing the membrane to UV curing for 140 s, a NOA membrane of 20 μm thickness is obtained.

The final fabrication step is the bonding of the cartridge membrane and body to realise the sealed microchannel. Optimal bonding is achieved by exposing to air plasma both sides for 60 s, at a pressure less than 0.1 Torr and with a plasma power of 20 W. The hard-cure of the whole cartridge under UV light for 2 h finalizes the bonding process. The result is a complete microfluidic cartridge that can have desired channel height and width, changing only the SU-8 deposition parameters. The height of the complete cartridge is also very flexible and depends on the height of the PDMS mould.

3. Characterisation and discussion

We studied the hydrophilic properties of the fabricated NOA 63 cartridge. A contact angle measurement is the common way to determine the degree of hydrophilicity of a material; the lower the contact angles, the higher the hydrophilicity. A high hydrophilicity in a microfluidic system entails easier filling of the channel with aqueous solutions, allowing easier manipulation or thinner walls around the channel. The contact angles on the NOA 63 surface, after the oxygen plasma treatment described above, are measured to be 30°. The induced hydrophilicity is more stable in NOA than in PDMS, with contact angles measured to be lower than 50° after three months of storing the NOA cartridge at room temperature and without further care, while after 200 min in air, the contact angle measured on PDMS is around 80° [11]. The effect of hydrophilicity is evident from Fig. 2: a NOA fabricated channel can be filled only by capillary forces, without the use of external pumps or syringes, even weeks after fabrication. In this case, the sealing membrane does not risk to be damaged during filling by syringes; the same cartridge fabricated in PDMS on the contrary has to be filled with liquid right after exposure to air plasma to avoid damages to the membrane.

When examining the optical characteristics of the material, we observed however some auto-fluorescence phenomena. We noticed high fluorescent emission in the range 515–565 nm, when the material is exposed to an excitation wavelength of 470 nm. This auto-emission is compared in Fig. 3 with the fluorescent auto-emission of PDMS and SU-8 similar cartridges. NOA 63 shows higher emissions in the considered wavelength spectrum, including the emission spectra of standard fluorescent dyes such as, for

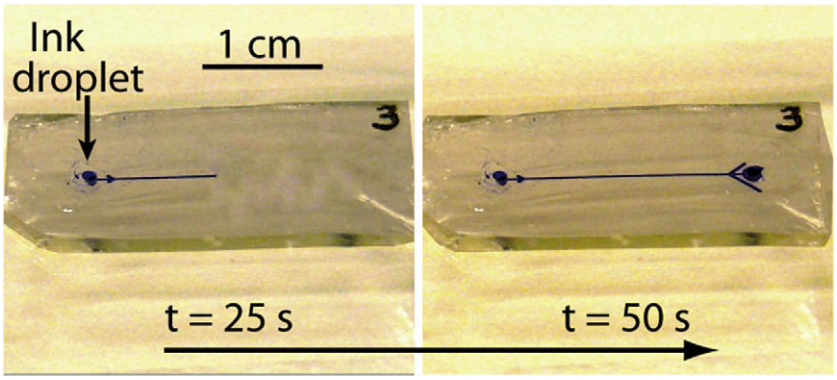

Fig. 2. The two pictures follow the temporal evolution of the filling of the microchannel. A droplet of ink is placed over the cartridge inlet. The ink rapidly starts to fill the microchannel, with an observed speed of 400 μm/s. The filling is achieved without need of external pumps or syringes, only exploiting capillary forces. The right-most picture of the cartridge also shows the good achieved sealing between the cartridge body and membrane, without any observable ink leakage.

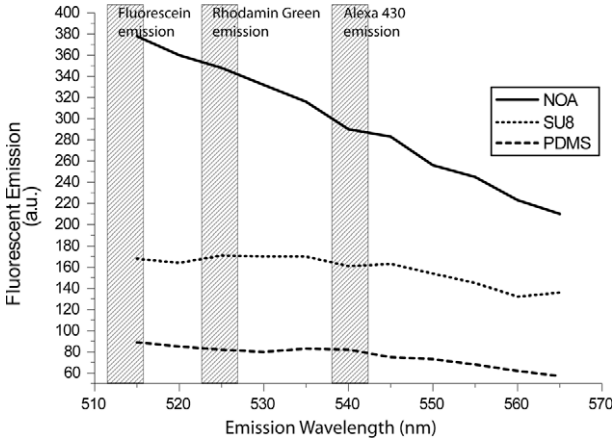

Fig. 3. Graph showing a comparison of the fluorescent emission from NOA 63, SU-8 and PDMS cartridges to different UV excitation wavelengths. The measurement was effectuated with an "Intensity 200" system, from Tecan Group Ltd. (Switzerland). The samples are exposed to a monochromatic excitation (wavelength of 470 nm) and material emission is studied from 515 to 565 nm. Typical emission ranges of three standard fluorescent dyes are indicated: Fluorescein (FITC), emitting around 515 nm, Rhodamine Green, emitting around 525 nm, and Alexa 430, emitting around 540 nm. In all of these three standard dyes emission zones, NOA 63 shows higher fluorescence emission than PDMS and than SU-8.

example, Fluorescein (FITC), Rhodamine Green and Alexa 430. Fig. 3 shows also that the auto-emission phenomenon tends to decrease towards the highest value of the spectrum; its relative value is always much higher than the auto-emission from PDMS cartridges in the same condition. This optical behaviour makes NOA 63 less suitable than PDMS for fluorescent detection systems, as its auto-fluorescence characteristics would decrease the sensitivity of the system, independently from the emission and excitation wavelength of the chosen fluorescent dye and from the detection setup characteristics. However, in the visible light region, the material does not present opacity and fluids or beads flowing in NOA 63 channels can clearly be distinguished. The material is thus suitable for other methods of detection, such as electrical or magnetic particle based detection.

To conclude, we presented a simple and fast fabrication method for microfluidic channels, which can lead to prototyping of complete cartridges by quick casting from a mould. The material is polymerised using UV curing. The produced microfluidic structure presents very good hydrophilicity properties after exposure to an oxygen plasma; this hydrophilicity is much more stable than PDMS hydrophilicity after plasma treatment. However, auto-fluorescence of NOA 63 fabricated cartridges makes them suitable only for non-fluorescent applications, because of the decreased sensitivity of a NOA 63 system used for fluorescent detection-based applications.

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